# LA-UR-22-26759

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**Title:** On the Determination of the Radiation Doses at Hiroshima

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**Intended for:** LANL Director's Colloquim

**Issued:** 2022-07-12

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# On the Determination of the Radiation Doses at Hiroshima

Dick Malenfant NEN-2

July 14, 2022

# LEST WE FORGET

**Those who cannot remember the past are condemned to repeat it”**

***“The life of Reason, Vol 1, Reason in Common Sense” George Santayana, 1863-1952.***

**“Those who cannot remember the past are condemned to repeat it”**

***“The life of Reason, Vol 1, Reason in Common Sense” George Santayana, 1863-1952.***

**“Given this unique experience at Hiroshima…it really is appalling to think that we stand here, 36 years later, debating orders of magnitude in the doses”**

**Jablon, Science 212 (19 June 1981):1364**

# Essentially all knowledge regarding the chronic effects of radiation exposure is derived from statistical analyses of the survivors of Hiroshima and Nagasaki

# HOWEVER

We were then, and are now, uncertain about the exposures.

That is:
We know the effects through observations and statistical analyses, but we can only estimate the doses!

# Other complications:

**Little Boy was truly unique-**

* It was never tested,
* measurements of yield were ambiguous,
* calculations of yield were not consistent,
* calibration measurements were not made, and could not be made.

Little Boy was exploded about 550 m above the ground and it was cylindrically symmetric.

Capture gamma-rays from iron, air, etc. are more penetrating than fission gamma-rays.

The massive case was an effective shield.

Radiation transport along the ground-air interface had to be considered.

Structures on the ground, and orientation of individuals, had to be considered.

**There were no dosimeters at Hiroshima and Nagasaki!**

**As a result, the radiation exposures must be calculated.**

**This requires a knowledge of the yield, spectra, attenuation, angular distribution, orientation, and etc.**

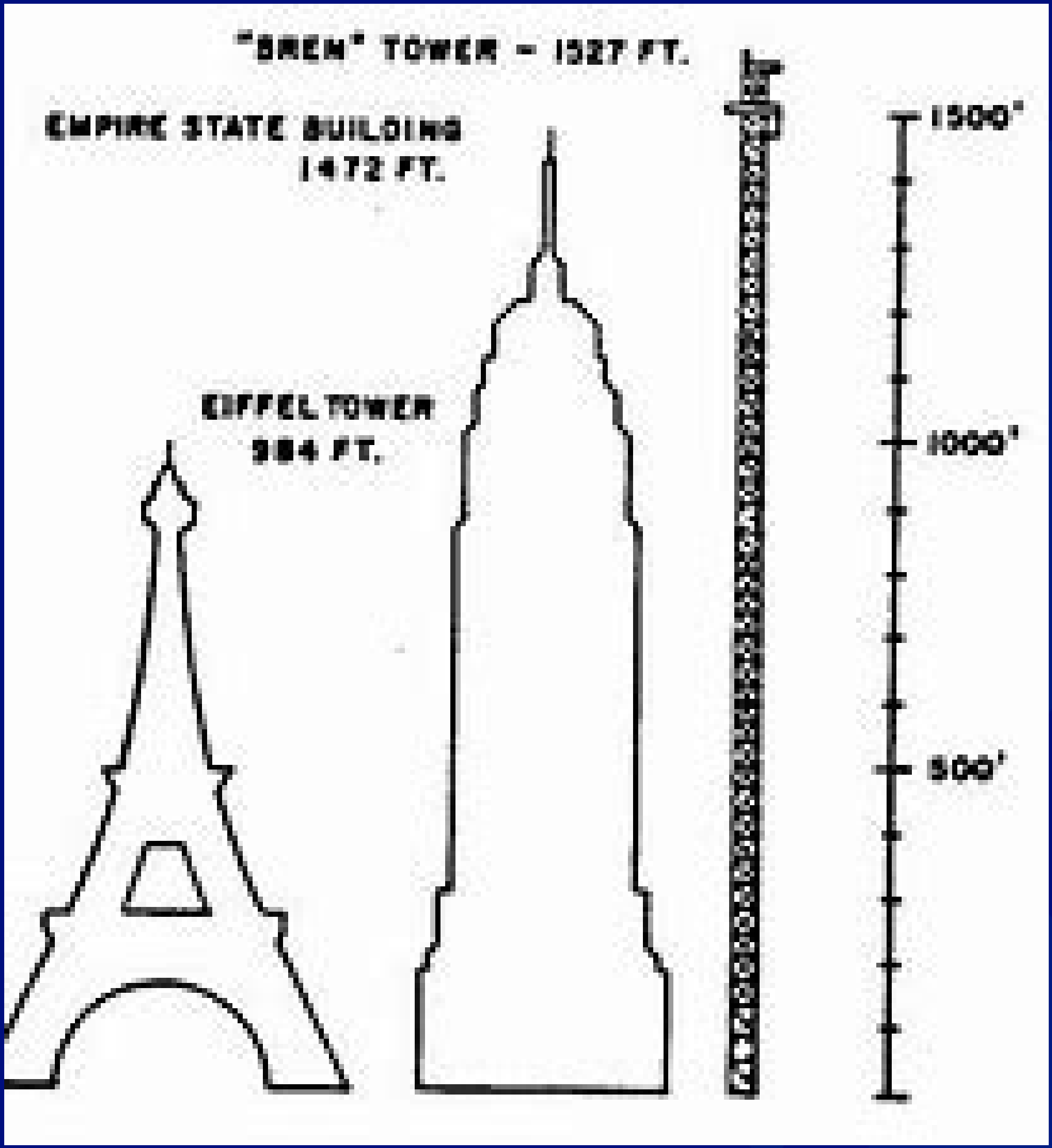
**Nevertheless, an attempt was made to evaluate the neutron and gamma-ray leakage spectra and angular distribution for a true replica of the Hiroshima weapon. In addition, by a strictly correct representation of the component parts, the configuration at first delay critical provided a benchmark for improved calculations of the yield.**

Several attempts were made to improve the estimates of radiation dose to the survivors:

The “Bare Reactor Experiment Nevada” (BREN) tower was erected at Yucca Flat in 1962. A bare burst reactor similar to Godiva was mounted on a hoist car to evaluate doses on the ground.

The 1,527 ft. tower was relocated to Jackass Flats following the Test Ban Treaty.

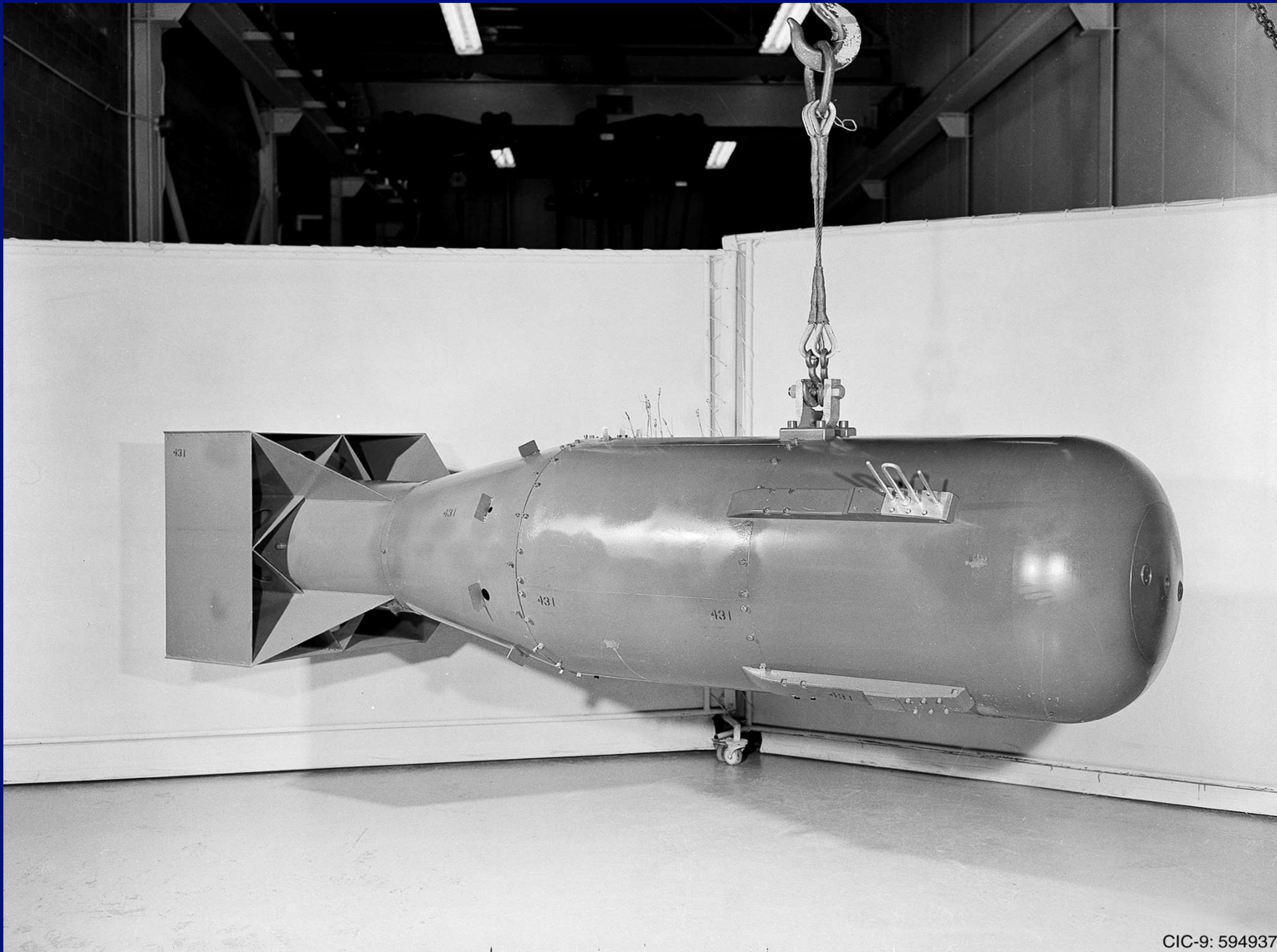
We used the facilities at the base of the tower to calibrate instruments for radiation measurements for the Rover Program.


"BREN" TOWER – 1527 FT.
EMPIRE STATE BUILDING
1472 FT.
EIFFEL TOWER
984 FT.
1500'
1000'
500'

**The reactor from the BREN experiments was "retired" to Oak Ridge where it was used for many years as the Health Physics Research Reactor (HPRR). It was a Godiva IV like bare uranium burst reactor. Like Godiva IV it could be operated in the burst mode or at steady state.**

**A typical burst resulted in $3 \times 10^{16}$ fissions (1 Mw-sec.).**

**After the HPRR was retired, measurements were made at TA-18 using Godiva IV.**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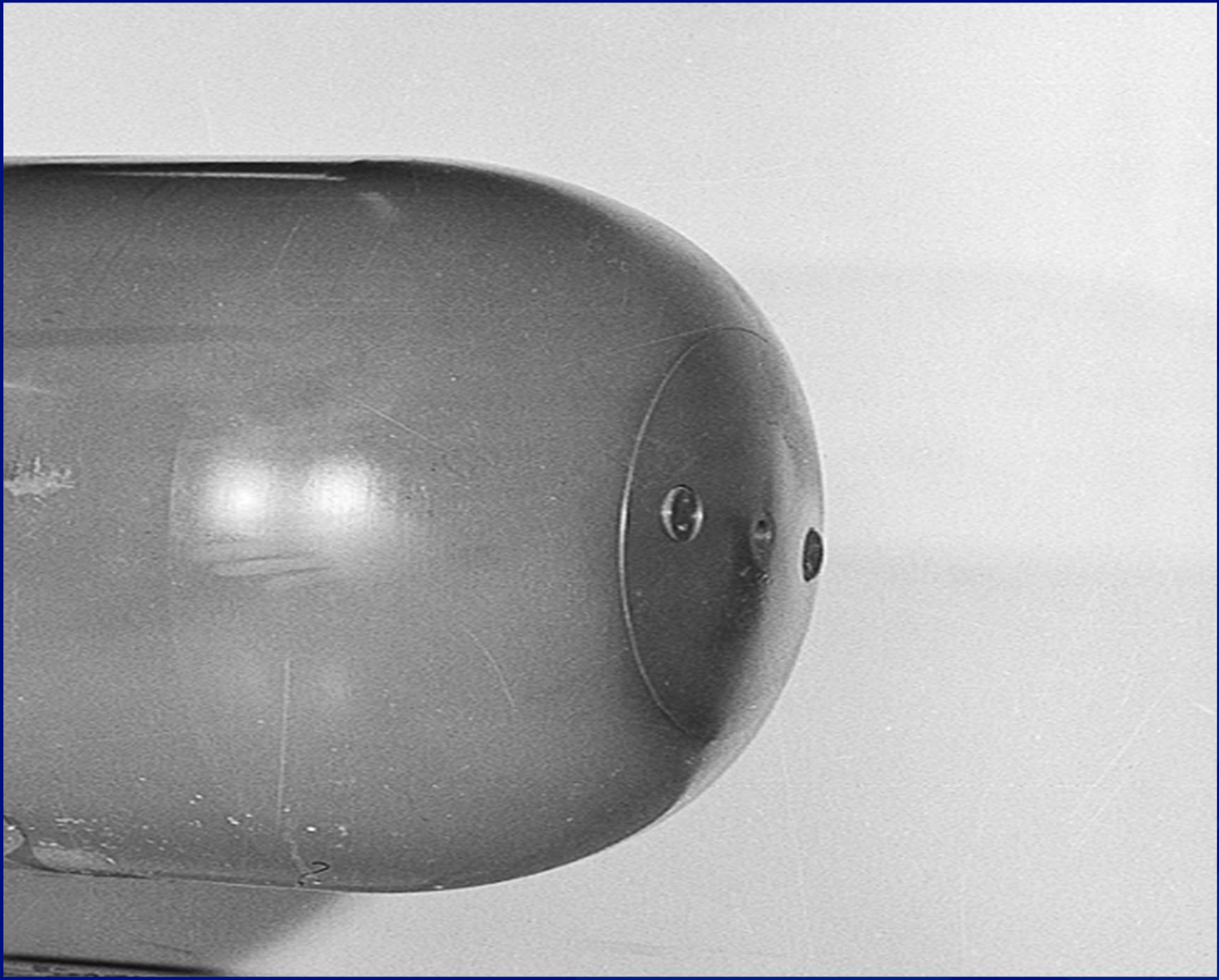
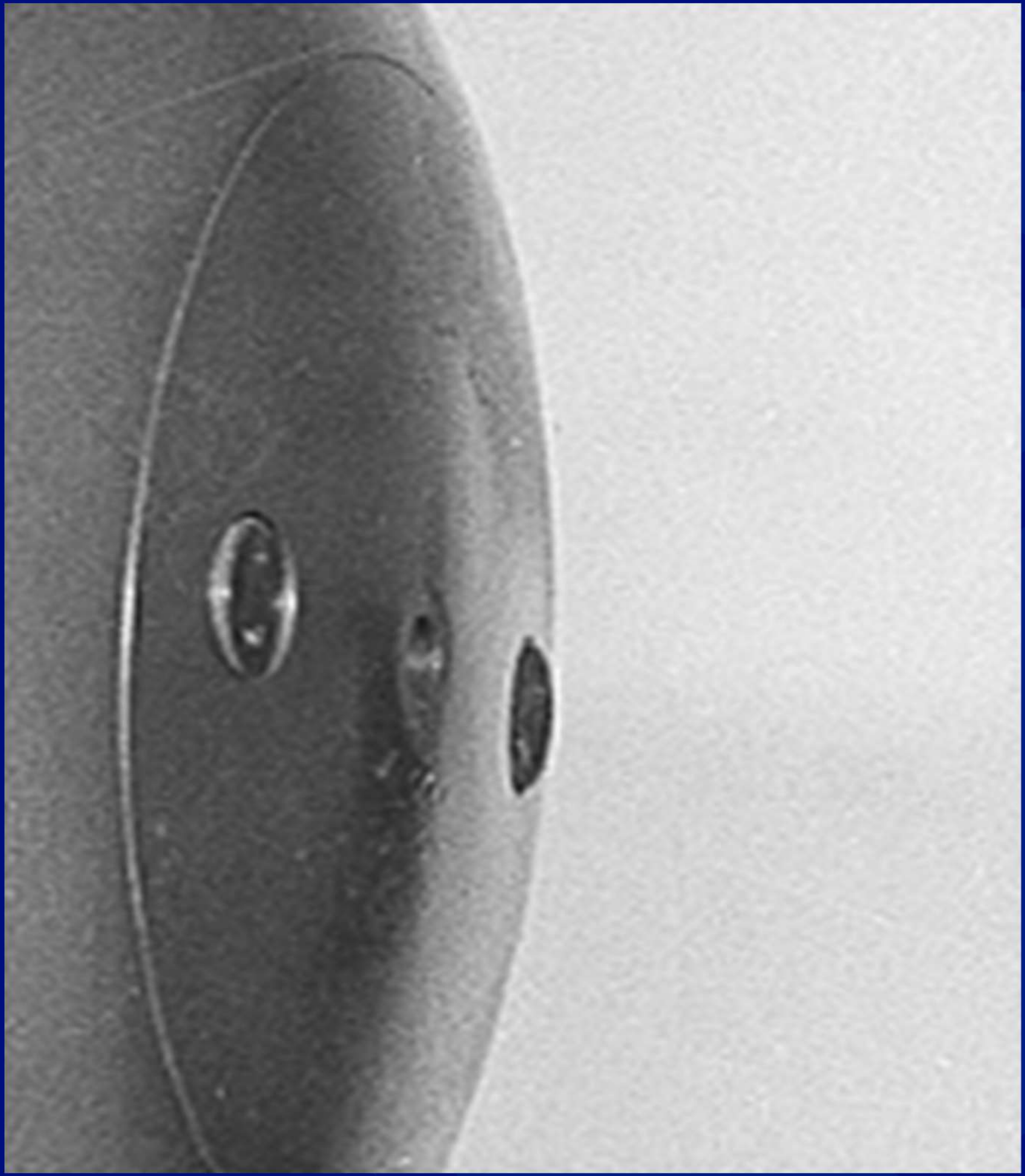
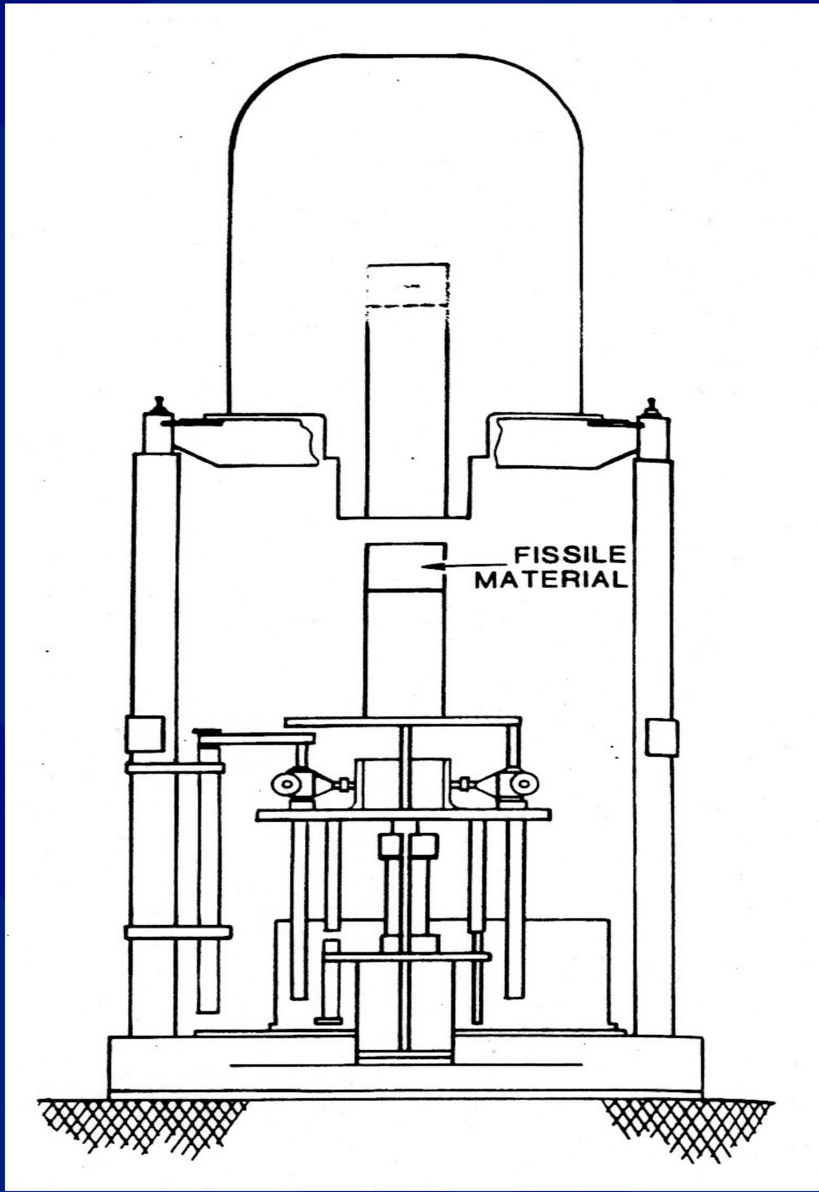




Cartoon of the Little Boy Replica on the Comet stand.

Two kinds of measurements were made:

- Separation of the components at first critical
- External neutron and gamma-ray spectra and radiation dose distribution




CIC-9: di99-1877

# TA-18, Pajarito Site

Cleaning and shortening the gun barrel
to facilitate the measurements

Gordon Hansen on the console operating the Little boy Replica

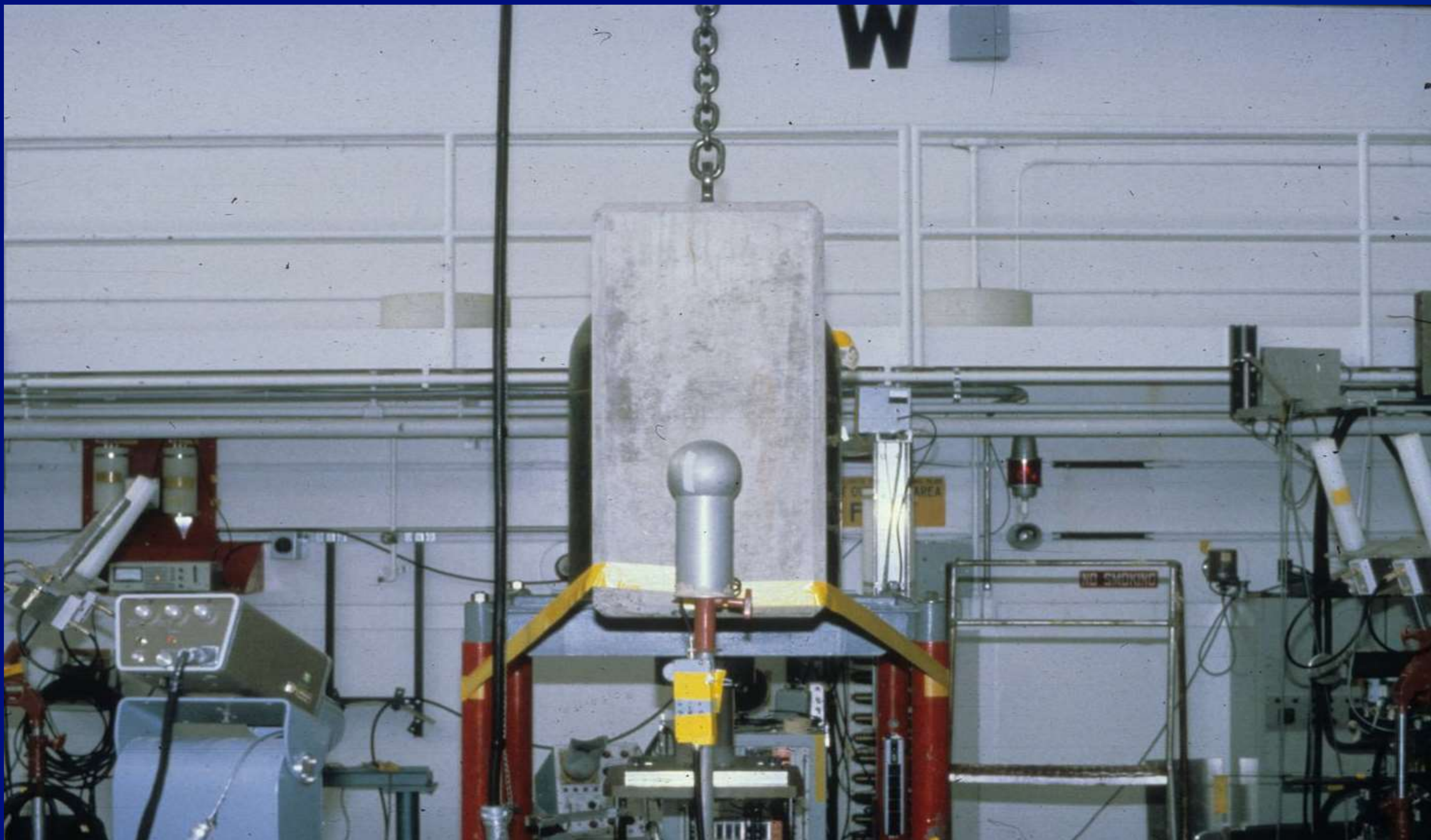
Benny Pena – On the console – Little Boy
In Kiva II on the T.V. monitor

# Little Boy replica in Kiva II

Dosimeters on Little Boy replica

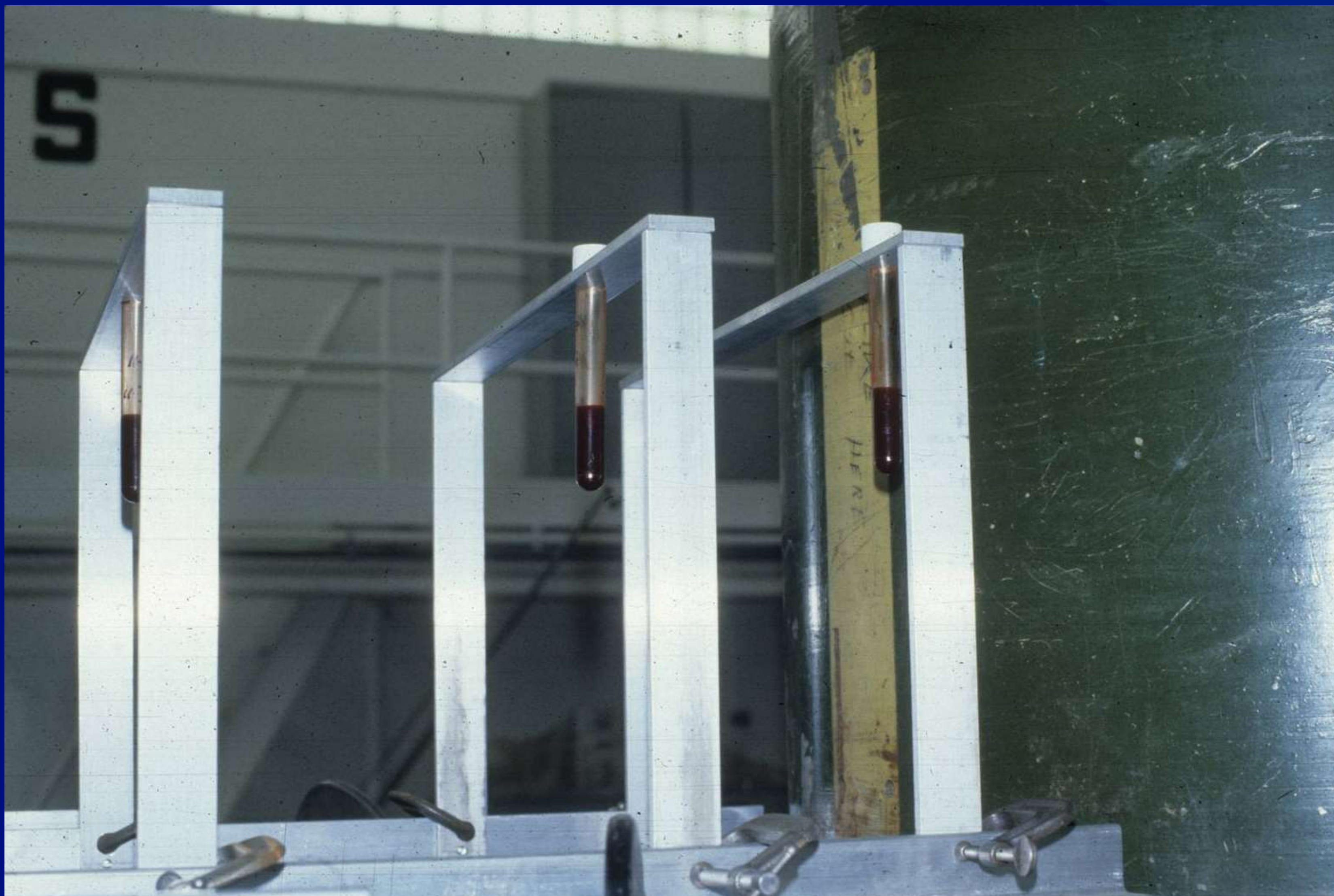
Note: standard ion chamber for power calibration

# Attempt to evaluate room return-both scatter and capture



# Tore Straume – LLNL Evaluating integrated dose by blood chromosome damage

The only blood samples available were his own!



To eliminate room return and to make measurements to a greater distance, the assembly was moved outside. The tent houses electronics for the Cutler-Shalev neutron detector

The formal portrait of the Little Boy replica.

Outside of Kiva II on the Comet Stand

Neutron dosimetry on an arc to measure angular distribution – LLNL measurement..
Note standard ion chamber for power calibration.

# Mac Forehand – LANL

Note startup counters to the left, and the standard counter to the right.

All systems go!
Angular traverse
with Bonner Balls

Bennie Pena and Al Evans, both LANL
Preparing for neutron spectra measurements
with the Cutler-Shalev detector.

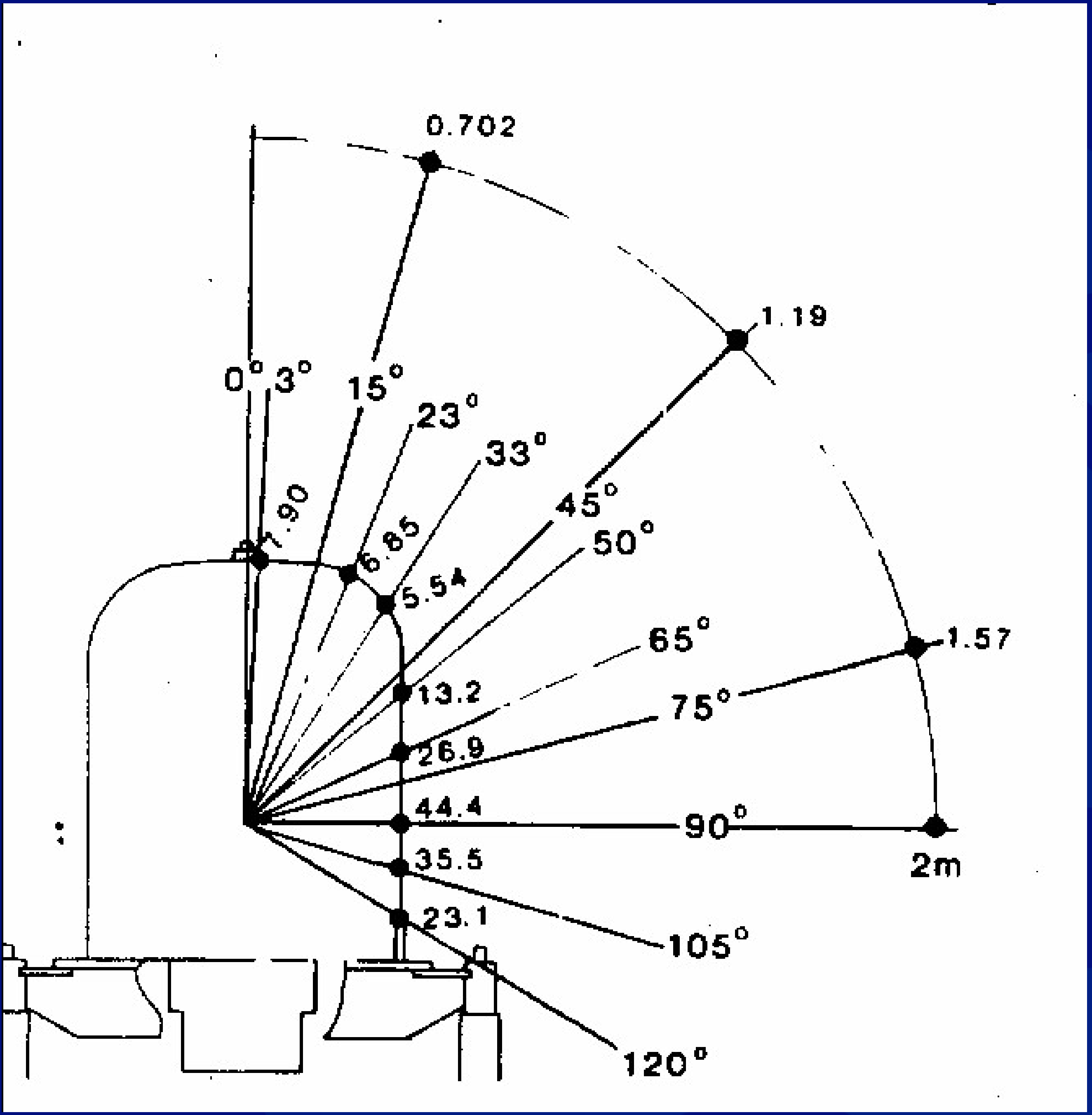
Measurements were made by LANL, LLNL, NRL, and US and Canadian universities.

Paul Whalen (LANL) back to camera in the foreground

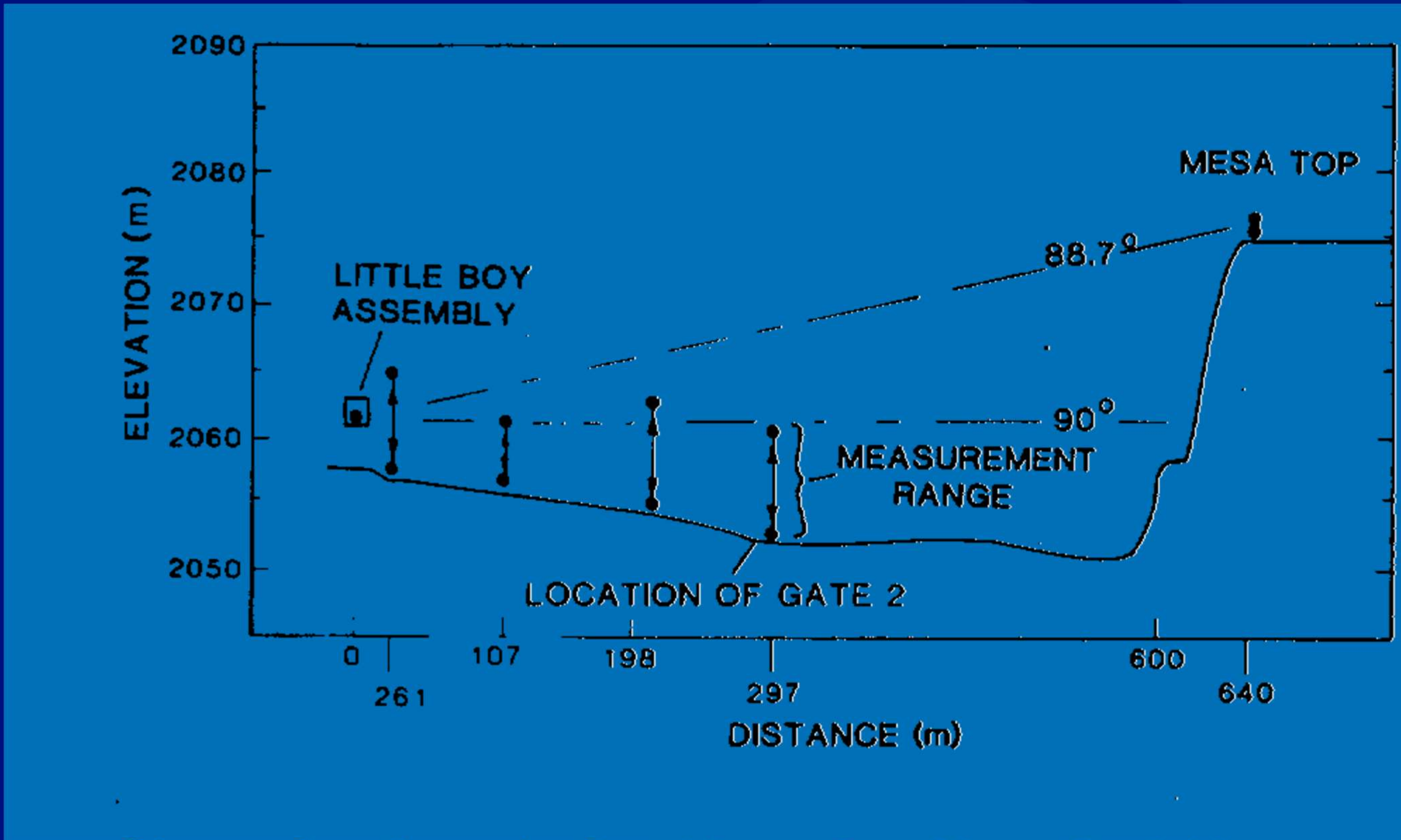
Measurements out to 1500 feet with Instruments mounted in a truck bed

# Dick Malenfant

# TLD gamma-ray Measurements (rem/10exp16 fissions)



# Location of the measurements near Kiva II
# Little Boy was operated outside of the Kiva



The calculations are far from simple:

1. Calculated estimates of the yield ranged from 12kt to 24 kt
2. Little Boy was cylindrically symmetric but it was 15 degrees off of vertical when it exploded 550 meters above the ground.
3. The massive tamper and shell were several mean-free-paths thick.

# The significance of uncertainty in cross sections

The casing of the Little Boy replica was about 70 cm in diameter by 90 cm long. Most of the 9500-lb assembly was concentrated in the casing that consisted primarily of steel. The radial and axial (dome end) leakage paths from the center of the fissile material were about 36 cm and 50 cm respectively. In terms of mean-free-paths using attenuation coefficients for 1-MeV gamma-rays and slab removal cross sections for neutrons, the following relationship holds.

Leakage Path in Mean-Free-Paths

| | Axial<br>50 cm iron | Radial<br>36 cm iron |
|---|---|---|
| Neutrons | 8.5 | 6.1 |
| Gamma-Rays | 23.8 | 16.9 |

## Uncertainty in Unscattered Leakages
## Due to 5% Uncertainty in Cross Section

| | Axial (%) | Radial (%) |
|---|---|---|
| Neutrons | 50 | 30 |
| Gamma-Rays | 120 | 85 |

# Calculations cont.

4. The cast iron case presented particular problems because of streaming paths through the anti-resonances.

5. Iso-dose contours on the ground were ellipitical rather than circular– requiring a knowledge of both distance and azimuth from ground zero.

# Calculations cont.

6. A significant contribution to the dose came from capture gamma-rays; particularly the very penetrating 10.83 MeV gamma-ray from nitrogen capture in air.

7. The ground-air interface resulted in additional complications

# Calculations cont.

8. The lethal radius for blast and fire exceeded the lethal radius for radiation. As a result, none of the survivors received a radiation dose greater than about 350 rads – less than the L/D 50-30!

# Calculations cont.

9. Shielding from structures on the ground, and orientation of those exposed, had to be taken into account.

10. There is no, unique, indicator of of radiation exposure, i.e. leukemia, cataracts, still births, cancers, and etc. occur in unexposed populations as well!

# Calculations cont.

11. By some measures, the average life expectancy in the exposed population exceeded the life expectancy in the control population – because weaker members of the exposed population were selectively eliminated by blast, fire, and trauma.

12. Although average family size in the exposed population was smaller than that in the control populations, the age at marriage was also increased resulting in reduced family size!

# Some units may illustrate the problem

The rad is defined as an absorbed dose of 100 ergs/gram.

1 r (Roentgen) = 87.7 ergs/gm air (assuming an ionization potential of 34.0 electron volts per ion pair)

The energy absorption per gram of tissue corresponding to 1 r is 96.5 ergs

# Biological dose is NOT a direct measurement

biological dose = physical dose x RBE

rem = rad x RBE

# Some units and conversion factors

1 rad (r) = 100 ergs/g
1 Gray (Gy) = 100 ergs
1 Sievert (Sv) = 100 rem
rem = rad x RBE
1 joule = $10^7$ ergs
1 cal = 4.184 joules
1 rad/s = 100 erg/g-s = $10^{-5}$ joules/g-s = $10^{-5}$ watt/g
$10^{-5}$ joules/g-s = $0.239 \times 10^{-5}$ cal/g-s
1 rad/s deposited in a material like water with a $c_p$ of 1 cal/g-°C results in a temperature increase of $3.6 \times 10^3$ s/hr x $0.239 \times 10^{-5}$ cal/g-s / 1 cal/g-°C $= 0.8604 \times 10^{-2}$ °C/hr;

That is, about 0.01 C/hr/rad/s!

# OBSERVATIONS

1. <u>None</u> of the contemporary standards for dosimetry provide a good representation of the radiation from Little Boy!

2. Although the rad is carefully defined and energy deposition can be measured, the effective radiation dose to mammals can only be inferred.

A Review of Thirty Years Study of
Hiroshima and Nagasaki Atomic Bomb Survivors*
JOURNAL OF RADIATION RESEARCH
SUPPLEMENT, 1975

"More than 90% of the survivors received much less than 10 rads from the A-bombs."

"A number of studies failed to demonstrate correlation of genetic abnormalities with A-bomb exposure, and these objective appraisals contributed not only to our overall knowledge, but to allaying of fears among those who were exposed to these bombs."

"All Japanese are well acquainted with the deleterious effects of radiation through mass media publications. Consequently, survivors and many other
Japanese anticipate the worst of radiation effects. Some survivors even experience social stigmata."

* Published by THE JAPAN RADIATION RESEARCH SOCIETY
The vast majority of the contributors to this document were Japanese

US-JAPAN WORKSHOP ON A-BOMB DOSIMETRY REASSESSMENT, HOROSHIMA, JAPAN 11/ 8-9/83 (LA-UR-83-3195)

Computer Applications in Health Physics – Proceedings of The Seventeenth Midyear Topical Symposium of the Health Physics Society, Pasco, Washington, February 5-9, 1984

S.F. Examiner (5/5/88)

Science, Vol.  212, 19 June 1981

Near-Twin of First A-Bomb Aids Radiation Studies, Albuquerque Sunday Journal, April 29, 1984.

Research News, 18 December 1987

Physics Today, September 1982

# Acknowledgements


Paul Robinson
Alan Carr
Mike Stevenson
Glen McDuff
Larry Booth
Allen Robitaille
Ray Pederson
Cal Moss
Manny Diaz
Tom Wimett
Payne Harris
Harold Agnew
Harlow Russ
Jim Jackson
Billy Claybrook

John Richter
Mac Forehand
Al Evans
Gorden Hansen
Benny Pena
Paul Whalen
Bill Preeg
John Kammerdiener
Rick Paternoster
Gene Plassmann
Fred Sanders
Marcia Lucas
Charlene Cappiello
All RCT Personnel

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Journal of Radiation Research Supplement 1975

Genetics, 2016 Aug: 203(4): 1505-1512

# References 3

Papers by Malenfant, Plassmann, Pederson, Moss, Lucas, Tisinger, Hamm, Forehand, Whalen, and Dowdy. (LA-UR #s are on file for abstracts and full papers)

**Computer Applications in Health Physics**

Proceedings of the Seventeenth Midyear Topical Symposium of the Health Physics Society
Pasco, Washington
February 5-9, 1984.

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Whalen, Soran, Malenfant, Forehand.

2ND US-JAPAN WORKSHOP ON A-BOMB DOSIMETRY REASSESSMENT

HIROSHIMA, JAPAN
11/8-9, 1983

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"Studies revise dose estimates of A-Bomb survivors," PHYSICS TODAY, September 1981, p. 17.

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"Atomic Bomb Doses Reassessed," RESEARCH NEWS, 18 December 1987.

# OBSERVATION

“Yet the general public, and indeed most scientists, are unaware of these data: it is widely believed that irradiated survivors suffered a very high cancer burden and dramatically shortened life span, and that their progeny were affected by elevated mutation rates and frequent abnormalities. In this article, I summarize the results and discuss possible reasons for this very striking discrepancy between the facts and general beliefs about this situation.”

*Genetics, 2016 Aug; 203(4): 1505-1512*
*Published online 2016 Aug. 5, doI:* [10.1534/genetics.116.191759](10.1534/genetics.116.191759)

Smithsonian

Imperial War Museum - London

National Atomic Museum

Damian Replica

Bradbury Museum